Memory retrieval: **Reactivating sensory cortex**

Sunil P. Gandhi

Associating information with vivid sensory cues aids recall of that information. New experiments help shed some light on the brain mechanisms of memory retrieval that make this mnemonic technique so effective.

Address: Molecular Neurobiology Laboratory, The Salk Institute, 10010 N Torrey Pines Road, La Jolla, California 92037, USA.
E-mail: sunil@salk.edu

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Ancient Greek orators often relied upon a powerful trick for learning lengthy speeches known as the method of *loci*. To memorize a list of arguments a speaker would practice them while, say, taking a walk to the local amphitheater, associating each argument with some monument along the way. During the performance, the speaker would imagine walking by each monument and in turn easily recall each associated argument. Apparently it is easier to navigate through sensory memories of the monuments than the semantic representations of the speech. This accounting presumes that sensory memories are recalled in a way that richly preserves their original perceptual properties. We might hypothesize, then, that sensory cortex reactivates during recall as the brain reassembles the perceptual context or episodic memory of the initial learning event. Two recent studies [1,2] may have found neural evidence for what the Ancient Greeks understood intuitively. By using functional imaging techniques to monitor brain activity, both groups found that some of the higher sensory cortical areas that initially encode a paired sensory stimulus are reactivated during recall of that stimulus. This finding raises interesting questions about the relationship between imagery and memory retrieval.

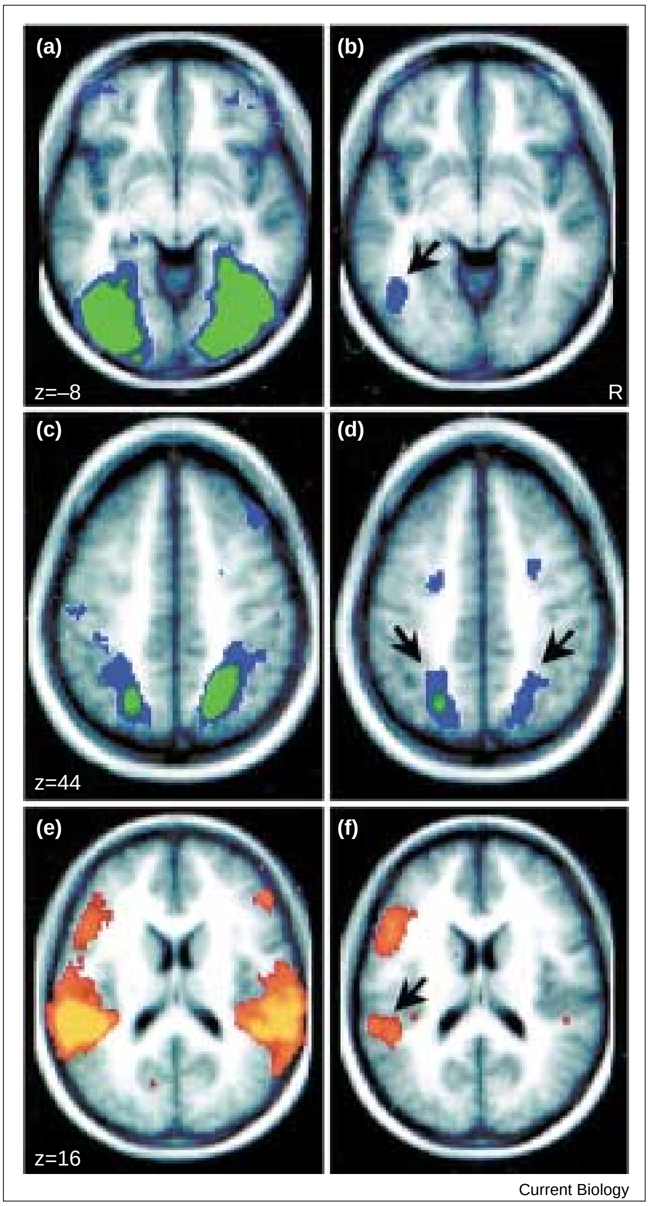
A major tenet in memory theory holds that memories are localized in the neural circuits that specialize in processing the information to be stored [3,4]. This principle has been demonstrated in various sensory system contexts. Consider the example of visual priming. Briefly flashing a picture to a subject will exact faster judgments about that picture in a subsequent trial, even though the subject may not recall seeing the flashed presentation. Brain activity in those visual areas selective to the picture's features decreases after the priming, likely reflecting an increased efficiency of processing [5]. Episodic memory, the learning and recall of paired associations, critically differs from priming in the way it is expressed: priming manifests itself as a possibly unconscious change in performance; episodic memory must be reported by the subject. Regardless of their sensory origin, episodic memories may be localized to a brain subsystem specialized for conscious access.

In the extreme, there are two possible patterns of brain activation during episodic sensory retrieval. First, it may be that, when a particular sensory memory is being retrieved, the areas that collectively process the original percept will be reactivated. Second, it is possible that episodic sensory memories just *seem* sensory in nature. Instead, they may get transformed and stored in a more abstract, symbolic memory store that would not involve the sensory cortex. To differentiate between these rival hypotheses, the brain activity during encoding and retrieval of episodic sensory information must be closely compared. Until now, few brain imaging studies have attempted such a direct comparison and met with success.

Using a clever design and a powerful new procedure for data analysis, Wheeler *et al.* [1] have shown that regions of visual cortex engaged in encoding of sensory information are reactivated during its retrieval. In the course of a few days, subjects first learned lists of written words that were each paired with either a picture or a sound. Later, the subjects' brain activity was monitored by functional magnetic imaging (fMRI) in two conditions. In the encoding condition, subjects were presented a word and its paired sensory stimulus, a picture or a sound. In the retrieval condition, the subjects viewed the word alone and had to report if it had been paired with a picture or sound. Two patterns of activation in sensory regions turned up in common between the encoding and retrieval conditions (see Figure 1). The first occupies the left fusiform gyrus, a putative site of object perception. A second site of reactivation appeared near the parietal-occipital junction, in brain areas that are associated with visual spatial operations and spatial imagery.

The finding of fusiform reactivation fits well with results from single-unit recordings in analogous monkey areas. Miyashita and colleagues [6,7] trained monkeys to associate pairs of computer-generated random images. The retrieval task involved first showing a monkey a cue image, waiting for some delay, and then testing the monkey's recall of the first image's paired associate by giving him a set of alternative matches. Miyashita and colleagues found cells that were selective for both a cue and its paired associate, as well as cells that were selective for only one of the two. Given a cell selective for image A only, then if A's paired associate was presented as the cue, the cell would show elevated activity during the delay period, as if anticipating the presentation of A. This delay-period activity can be seen as the single-cell correlate to the

Figure 1



Brain activity maps, measured using fMRI, are overlaid in color on brain structure in black and white. Each image is a slice taken horizontally at three different inferior/superior positions. On the left are shown patterns of brain activity during perception of words paired with either pictures or sounds. Images **(a,c)** show activity during picture perception. The most inferior slice (a) shows activity in primary and secondary visual cortex. The more superior slice (c) shows activity in superior occipital and parietal cortex. Image **(e)** shows brain activity during sound perception; taken more centrally, this slice shows activation of primary and secondary auditory cortex. On the right are shown patterns of activity active during perception of pictures or sounds that were also active during memory retrieva. Images **(b,d)** show reactivation of two circumscribed areas during recall pointed to with black arrows in left fusiform gyrus (b) and bilateral parieto-occipital cortex (d). Image **(f)** shows reactivation of secondary auditory cortex during recall of sounds.

reactivation effects found in the imaging studies. A more recent study [8] found that the delay activity can be extinguished if, during the delay, the task were to switch from associate matching (A with A's associate) to identity matching (A with A), further bolstering the relevance of the delay activity to memory retrieval.

Memory retrieval can reactivate auditory as well as visual brain areas. In the trials that tested recall of word–sound pairings, Wheeler *et al.* [1] found that a restricted region of secondary auditory cortex was reactivated but primary auditory cortex was not (see Figure 1). Unfortunately, the functional organization of the auditory cortex is poorly understood, so it is hard to interpret to what extent the reactivation was appropriately selective for the sounds used in the task. In a second study, Nyberg *et al.* [2] also employed sound–word pairings and found secondary auditory cortex reactivation. The two experiments disagreed, however, on which side of the brain showed a more pronounced retrieval reactivation. Hemispheric asymmetries in memory imaging studies are often hard to interpret, because they are so sensitive to the details of the behavioral task and to variability across subjects.

Intriguingly, in the Nyberg *et al.* [2] study the sensory cortex reactivation also appeared incidentally when there was no task demanding retrieval of the paired sensory stimulus. For the main, *intentional* retrieval task, subjects had to report whether or not a word had been paired with a sound. As mentioned above, secondary auditory cortex was reactivated in this condition. For the *incidental* retrieval task, Nyberg *et al.* asked subjects the simpler task of answering if a word was part of the original study list. Strikingly, for trials involving word–sound pairs, the same auditory region reactivated during the *incidental* task as for the *intentional* task. It would be fascinating to know if subjects became aware of the sound when its representation was reactivated during the *incidental* task.

In both studies [1,2], only higher-level sensory areas were reactivated during retrieval, but upon further investigation lower-level retrieval effects may be uncovered. Scientific opinion on the extent of attention's influence in the hierarchy of sensory cortical processing has changed in recent years [9]. At first, only higher visual areas were reported to show attentional effects. But with the careful refinement of the behavioral conditions, experimenters have subsequently shown that attention affects the entire visual cortical hierarchy including primary visual cortex [10]. If the encoding and retrieval tasks were redesigned to use paired sensory stimuli consisting of more elemental features than the pictures and sounds employed by both groups [1,2], then retrieval reactivation might turn up in lower sensory areas.

When reciting their oratory, the Greeks did not actually provoke their memories with real visual cues, instead they imagined walking among the monuments. Instructing subjects to close their eyes and vividly imagine visual features elicits activity throughout visual cortex, possibly including primary visual cortex [11]. Imagining a stone monument appears to work as well as actually seeing it to reactivate memories for the speech. It follows that imagery is activating the same memories as those engaged in the retrieval tasks from the imaging studies. So it could be that sensory memories are actually stored elsewhere in the brain in some abstract associative store, and then somehow the brain mechanisms in common between retrieval and imagery project them back into sensory cortex. Hopefully, future studies as insightful as these new ones [1,2] will sort out the brain mechanisms shared between imagery and memory retrieval and definitively answer how episodic memories are recalled.

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